Energy, Mines and Resources Canada | Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology | Centre canadien de la technologie des minéraux et de l'énergie

A PRELIMINARY INVESTIGATION ON SUPERPLASTICIZED HIGH-VOLUME SLAG CONCRETE

E. Douglas, A. Bilodeau and V.M. Malhotra
Mineral Processing Laboratory

December 1989

This document is an unedited internal report prepared primarily for discussion and documentation purposes. It does not represent a final expression of the opinion of the Canada Centre for Mineral and Energy Technology (CANMET)

Ce document est un rapport provisoire non-révisé et rédigé principalement pour fin de discussion et de documentation interne. Il ne représente nullement l'expression définitive de l'opinion du Centre canadien de la technologie des minéraux et de l'énergie (CANMET)

14 pp

Project: 30.37.01
Use of Supplementary Cementing Materials in Concrete

MICROMEDIA

MINERAL SCIENCES LABORATORIES
DIVISION REPORT MSL 89-136 (IR)

90-03952/

A PRELIMINARY INVESTIGATION ON SUPERPLASTICIZED HIGH-VOLUME SLAG CONCRETE

by

E. Douglas*, A. Bilodeau** and V.M. Malhotra***

ABSTRACT

Replacement of high-volumes of portland cement by ground granulated blast-furnace slag in concrete yields a product with low heat of hydration resulting in minimal thermal expansion and cracking. Also, resistance of these concretes to chloride corrosion and sulphate attack is greatly improved compared to portland cement concrete.

The use of superplasticizers is necessary to attain acceptable workability of portland cement blast-furnace slag mixtures with low water-to-binder ratios, yielding concretes of low permeability and, therefore, enhanced durability.

The binder of the first concrete mixture consisted of 20% portland cement and 80% ground granulated blast-furnace slag and that of the second concrete mixture consisted of 10% portland cement and 90% slag. The water to binder ratios of the concrete mixtures were 0.29 and 0.33, respectively. The amount of superplasticizer required to obtain an acceptable workability in the second mixture was about half of that required in the first mixture. The concrete from the mixture incorporating 90% slag yielded lower compressive strengths that the concrete from the mixture incorporating 80% slag.

Keywords: Ground granulated blast-furnace slag, slag concrete, superplasticizer

---

*Research Scientist, **Engineer, ***Head, Concrete Technology Section, Mineral Sciences Laboratories, CANMET, Energy, Mines and Resources Canada, Ottawa, Ontario, K1A 0G1.

ÉTUDE PRÉLIMINAIRE SUR LE BÉTON SUPERPLASTIFIÉ À FORTE TENEUR EN LAITIER

par

E. Douglas*, A. Bilodeau** et V.M. Malhotra***

RÉSUMÉ

Le remplacement dans le béton d'une grande proportion du ciment par du laitier granulé et broyé de haut-fourneau donne un produit avec une faible chaleur d'hydratation ce qui résulte en très peu d'expansion thermique et de fissuration. De plus, la résistance à la corrosion due aux chlorures ainsi qu'à l'attaque des sulfates est beaucoup améliorée par rapport au béton de ciment portland.

L'utilisation de superplastifiants est nécessaire à l'obtention d'une maniabilité acceptable pour ces mélanges de béton de ciment portland et laitier de haut-fourneau ayant de faibles rapports eau-liant, ceci produit des bétons démontrant une faible perméabilité et donc une durabilité améliorée.

Deux mélanges de béton dans lesquels le liant contenait respectivement 80 et 90 % de laitier en remplacement du ciment furent réalisé. Les propriétés du béton frais et durci ont été déterminées. Le fait d'augmenter la proportion en laitier à 90 % et le rapport eau-liant à 0,33 tout en diminuant la quantité de superplastifiant à moins de la moitié de celle requise dans le mélange contenant 80 % de laitier a résulté en une baisse significative des résistances en compression.

Mots-clés: laitier granulé et broyé de haut-fourneau, béton de laitier, superplastifiant

---

*Chercheur scientifique, **Ingénieur, ***Chef, Section de la technologie du béton, Laboratoires des sciences minérales, CANMET, Énergie, Mines et Ressources Canada, Ottawa (Ontario), K1A 0G1.

INTRODUCTION

Concretes with high content of ground granulated blast-furnace slag have low heat of hydration and high resistance to corrosion and sulphate attack (1,2,3,4). In Europe (5,6,7) and in Japan (8), the use of high-volume slag concretes is recommended for a wide range of applications. In recent years, the use of blast-furnace slag in concrete manufacturing in Canada has become increasingly popular and specifications for its use have been incorporated in CSA standards (9).

In this preliminary study, two high-volume-slag, low water-to-binder ratio concretes, were made incorporating a superplasticizer. The properties of the fresh and the hardened concretes are reported.

SCOPE OF INVESTIGATION

Two concrete mixtures were made with blends of portland cement and ground granulated blast-furnace slag. The binder of the first concrete mixture consisted of 20% portland cement and 80% slag and that of the second concrete mixture consisted of 10% portland cement and 90% slag. The water-to-binder ratios were 0.29 and 0.33, respectively, and a superplasticizer was added to obtain acceptable workability. No attempt was made to incorporate an air entraining admixture.

A number of 152 x 305-mm cylinders and 76 x 102 x 406-mm prisms were cast for compressive and flexural strength testing at different ages.

CONCRETE MIXTURES

Materials

Two concrete mixtures were made in the CANMET laboratory in September 1989 using the following materials:

Portland cement. A CSA Type 10 portland cement was used in the two concrete mixtures and its chemical and physical characteristics are shown in Table 1.

Slag. A ground granulated blast-furnace slag from northern Ontario was used in the two mixtures. The fineness, chemical composition, glass content and slag activity index are shown in Table 2.

Superplasticizer. A naphthalene based superplasticizer (Mighty 150) was added to both mixtures.

Aggregates. The coarse aggregate used was crushed limestone with a maximum size of 19 mm and the fine aggregate was natural sand. The grading and physical properties of both the fine and the coarse aggregates are shown in Tables 3 and 4.

Mixture Proportioning

The first mixture (mixture 1) was made with a binder consisting of 80% ground granulated blast-furnace slag and 20% portland cement with a water-to-binder ratio of 0.29. The amount of superplasticizer added was 10.7 kg/m^3.

The second mixture (mixture 2) was made with a binder content of 90% slag and 10% portland cement. The water-to-binder ratio was 0.33, and the amount of superplasticizer added was 4.6 kg/m^3. The total binder-to-aggregate ratio in both mixtures was approximately 1:4.7. The mixture proportions of both concretes are shown in Table 5.

PREPARATION AND CASTING OF TEST SPECIMENS

For both mixtures, a number of 152 x 305-mm cylinders were cast to determine compressive strengths up to 91 days, and 76 x 102 x 406-mm prisms were cast for testing in flexure at 7 and 91 days. All cylinders and prisms were cast in two layers, each layer being compacted using a vibrating table.

After casting, all the moulded specimens were covered with water saturated burlap and left in the casting room at 23 ± 1.7°C for 24 h. The cylinders were then demoulded and after density measurements they were transferred to a moist curing room until required for testing.

TEST RESULTS

The properties of the fresh and hardened concretes for mixtures 1 and 2 are shown in Tables 5 and 6. The water-to-binder ratios, amounts of superplasticizer added and slump values for both mixtures are included.

DISCUSSION OF TEST RESULTS

With a water-to-binder ratio of 0.29 and addition of superplasticizer, the concrete from mixture 1 had acceptable workability as measured by a 175 mm slump. The amount of superplasticizer required to obtained that slump was 10.7 kg/m^3, which was considered excessive. In concrete mixture 2, the water-to-binder ratio was increased to 0.33. The addition of 4.7 kg/m^3 of superplasticizer to the mixture 2 resulted in a 215 mm slump. The compressive strengths determined in the specimens of concrete from mixture 2 were lower than those determined in specimens of concrete from mixture 1, at all ages. In this initial exploratory study, no attempt was made to increase the water-to-binder ratio in mixture 1, in order to lower the amount of superplasticizer required to obtain an acceptable workability.

Nor was there an attempt to decrease the water-to-binder ratio in mixture 2, with some loss of slump but still with acceptable workability, in order to obtain compressive strengths of the same order as those of concrete from mixture 1.

CONCLUDING REMARKS

The following observations may be made from the limited investigations performed:

1. A high-volume blast-furnace slag concrete with up to 80% slag, low water-to-binder ratio and large amounts of superplasticizer develops compressive and flexural strengths, at 7 days and beyond, comparable to that of a non-superplasticized portland cement concrete with an equivalent cementitious content.

2. A concrete with 90% portland cement replacement by slag, with a water-to-binder ratio 0.04% higher than the concrete with 80% slag, requires less than half of the amount of superplasticizer to attain acceptable slump, but it yields lower compressive strengths, especially at 1 day.

3. Comparing the slump values measured in the two concrete mixtures, it is suggested that the mixture incorporating 90% slag could have been proportioned with a lower water-to-binder ratio, probably improving the compressive strengths.

RECOMMENDATIONS

Research should be carried out on the optimization of the proportioning of the concrete mixtures with the addition of naphthalene and of melamine based superplasticizers.

REFERENCES

1. Roy, D.M. "Hydration, microstructure and chloride diffusion of slag-cement pastes and mortars", Proceedings of the Third International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Trondheim, Norway, ACI SP-114, Vol. 2, pp. 1265-1281, Editor, V.M. Malhotra, 1989.

2. Decter, M.H., Short, N.R., Page, C.L. and Higgins, D.D. "Chloride ion penetration into blended cement pastes and concrete", Proceedings of the Third International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Trondheim, Norway, ACI SP-114, Vol. 2, pp. 1399-1411, Editor, V.M. Malhotra, 1989.

3. Cook, D.J., Hinczak, I., Jedy, M. and Cao, H.T. "The behaviour of slag-cement concretes in marine environment - chloride ion penetration", Proceedings of the Third International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Trondheim, Norway, ACI SP-114, Vol. 2, pp. 1467-1483, 1989.

4. Frearson, J.P.H. "Sulphate resistance characteristics of combinations of portland cements and ground granulated blast-furnace slags", Messrs. Sandberg Report X/133/SR/JF33, 1989.

5. British Standards Institution - BS6699, 1986 - "British Standard specification for ground granulated blast-furnace slag for use with portland cement", BSI, London, 1986.

6. DIN 1164, Part 1, "Portland, Eiseuportland, Hochopen und Trabzement", November 1978.

7. Bulletin Officiel du Ministére de l'Equipement et de l'Amenagement du Territoire, Circulaire N°. 77-91, 17 juin, 1977.

8. Nagatabi, S., Madrida, A., Yamamoto, Y. and Uomoto, T. "Japanese recommendation for the use of ground granulated blast-furnace slag in concrete as an admixture", Proceedings of the Third International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Trondheim, Norway, ACI SP-114, Vol. 2, pp. 1657-1676, Editor, V.M. Malhotra, 1989.

9. CSA Standard CAN/CSA-A23.5-M86, "Supplementary cementing materials".

Table 1 - Chemical and Physical Characteristics of Portland Cement

Chemical Analysis (%)*		Physical Properties	
SiO_2	21.3	Normal consistency (ASTM C 187)	22.8%
Al_2O_3	4.3		
Fe_2O_3	2.3	Vicat set time (ASTM C 191)	
MgO	3.6	Initial	129 min.
CaO	62.8	Final	210 min.
Na_2O	0.47		
K_2O	0.50	Fineness (ASTM C 184, C 430)	
SO_3	2.92	Minus 75 μm	98.7%
CaO (free)	0.02	Minus 45 μm	91.3%
LOI	1.69		
Insol. residue	0.20	Blaine (ASTM C 204)	4070 cm^2/g
Bogue Composition:		Compressive strength of mortar Cubes (ASTM C 109):	
		1 d	10.7 MPa
C_3S	53.2	3 d	22.0 MPa
C_2S	21.0	7 d	26.9 MPa
C_3A	7.5	28 d	35.0 MPa
C_4AF	7.0		
CaO	0.02	Autoclave Expansion	0.09%
MgO	3.6	*ASTM C 151	
CSH_2	6.3		
Total	98.6		

*Method ASTM C 114; Fe by atomic absorption spectroscopy
Analysis total including minor oxides, Na_2O and K_2O, insol. residue, and LOI not associated with gypsum = 100.3%.

Table 2 - Physical Properties and Chemical Analysis of the Ground Granulated Blast-Furnace Slag

Description of Test		Slag
<u>Fineness</u>		
Passing, 45 μm, %		97
Surface area, Blaine, m^2/kg		460
<u>Chemical analysis</u>		
SiO_2		38.00
Al_2O_3		8.74
Fe_2O_3		0.55
CaO		32.00
MgO		18.60
SO_3		2.45
K_2O		0.76
Na_2O		0.22
Loss on ignition		1.98
Glass content		90.3
Compressive strength of mortars (50% PC) ASTM C 989	7 days	18.7
	28 days	31.4
Slag activity index, % (ASTM C 989)	7 days	69.8
	28 days	100.0

Table 3 - Grading of Aggregates

Coarse Aggregate		Fine Aggregate	
Sieve size	Cumulative Percentage Retained	Sieve size	Cumulative Percentage Retained
19.0 mm	0.0	4.75 mm (No. 4)	0.0
12.7 mm	35.0	2.36 mm (No. 8)	10.0
9.5 mm	60.0	1.18 mm (No. 16)	32.5
4.75 mm	100.0	600 μm (No. 30)	57.5
		300 μm (No. 50)	80.0
		150 μm (No. 100)	94.0
		pan	100.0

Table 4 - Physical Properties of Aggregates

	Coarse Aggregate*	Fine Aggregate**
Specific Gravity	2.69	2.70
Absorption, %	0.82	1.1

*Crushed limestone
**Natural sand

Table 5 - Mixture Proportions and Properties of Fresh Concrete

Mixture No.	W/(C+S)	S/(C+S)	Mixture Proportions						Properties of Fresh Concrete		
			Sand kg/m^3	Coarse Agg. kg/m^3	Water kg/m^3	Cement kg/m^3	Slag kg/m^3	Super-plasticizer kg/m^3	Unit Wt. kg/m^3	Slump mm	Air Content %
1	0.29	0.80	749	1223	115	83	332	10.7	2510	175	0.7
2	0.33	0.90	723	1182	130	41	367	4.6	2445	215	1.3

Table 6 - Properties of Hardened Concrete

Mix No.	W/(C+S)	Density of Cylinders (kg/m^3)	Compressive Strength (MPa)*				Flexural Strength** (MPa)	
			1d	7d	28d	91d	14d	91d
1	0.29	2505	4.9	33.7	41.4	47.7	7.5	7.6
2	0.33	2460	1.8	22.8	27.5	32.2	6.3	5.5

*Test was done on 152 x 305-mm cylinders
**Test was done on 76 x 102 x 406-mm prisms